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III - OPTICAL MEASUREMENT SYSTEMS

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This section of the report describes some of the areas of research conducted at the Lewis Research Center on optical measurement techniques for propulsion systems research. Most of the optical techniques used to measure gas parameters depend on very inefficient light scattering principles and therefore require the high light intensities provided by lasers. Significant advances in laser technology, together with the availability of sensitive photodetection systems, provide much of the impetus for research in optical diagnostic techniques.

These nonintrusive measurement systems are needed in applications where traditional sensors would excessively disturb the measured parameter or where an intrusive sensor could not survive the environmental conditions under which the measurement must be made. As the operating temperatures of propulsion systems increase and the size of engine components and flow passages decreases, the need for optical measurement systems becomes increasingly important.

The goal of the research described here is to enhance the capabilities of nonintrusive research instrumentation to meet the special needs of aeropropulsion research. Optical techniques are being used to validate analytical codes and to verify the performance of aeropropulsion components and systems.

Listed in table III-I are some important areas of current research, together with two recently completed efforts, the rainbow schlieren and the hot section viewing system. The fluid and structural parameters measured by the listed techniques are also shown. Several of the areas will be described in more detail in this paper to illustrate the aeropropulsion instrumentation needs we are trying to fill. Other research areas are discussed in references III-1 to III-3.

Applying laser anemometry to aeropropulsion research facilities presents many challenges for the instrumentation research (refs. III-4 and III-5). Desired characteristics include the ability to measure flow along three axes through a very limited viewport, to make velocity measurements near surfaces, and to make measurements efficiently in a turbulent or highly accelerating flow. Both the enabling technology required to achieve these capabilities and the development of new systems are being addressed in Lewis's instrumentation program. As an example of the former research, the use of fiber optics in laser anemometry systems is currently being investigated to meet the problems of high vibration and acoustic noise levels, which are commonly encountered in aeropropulsion research and test facilities (ref. III-6). Two new laser anemometer (LA) systems developed to meet specific needs are the three-axis LA and the four-spot LA. The three-axis LA system (ref. III-7) was designed to measure the radial component of flow in addition to the axial and circumferential components through a single optical viewing port in a turbine stator cascade facility. The system uses a Fabry-Perot interferometer technique in conjunction with the more common dual-beam fringe configuration. The annular vane ring shown in figure III-1 has a contoured hub to enhance the radial velocity component. Velocity data for each axis and total velocity are shown in figure III-1(c) and compared with the predicted values obtained with a computer code. Total mean velocity and the three components (ratioed to a Mach 1 velocity parameter) are plotted for the passageway between two vanes.

The four-spot LA system (refs. III-8 and III-9) was developed at Lewis in conjunction with Case-Western Reserve University. It is a laser transit anemometer (LTA) wherein velocity is determined by measuring the time required for seed particles to cross the gap between closely spaced laser beams. The four-spot system has the feature of wide flow acceptance angle (necessary for measurements in turbulent flows) while retaining the LTA advantages of close-to-wall measurements and small seed particle compatibility. The use of orthogonally polarized optics in generating the probe volume (which results in the four-beam configuration named here as "four spot") more precisely defines the time of crossing of a seed particle and hence improves the accuracy of the measurement over a wide range of velocities.

The four-spot LA has been tested in a small facility capable of generating hot (1000 K) turbulent flows, as shown in figure III-2. Velocity surveys were obtained to within 200 μm of a turbine vane surface inserted into the test flow, as compared with a typical value of about 1 mm obtained with fringe-type LA systems. Other tests demonstrated velocity measurements to Mach 1.3 with 0.5-μm seed particles.

Two paths to higher performance engines are to increase the operating temperatures in the combustor and to decrease the weight of engine components. The combustor viewing system (ref. III-10) was designed as a diagnostic tool for use in studying internal processes in high-temperature, high-pressure combustors. One of the primary goals was to study the onset of combustor liner failures such as cracking. Images of the combustor interior are transmitted to a photographic or video camera through a coherent bundle of 75 000 10-μm-diameter fibers. Also included are two 1-mm-diameter fibers to provide illumination from a laser or arc lamp, for those applications where there is no natural illumination or where the natural radiation is unsuitable and is replaced as the illumination source by pulsed illumination and subsequent synchronous detection. The rotatable, retractable probe is purged with N_2 to keep the tip clean and water cooled to allow operation at environmental temperatures above 2000 K.

In the figure III-3 photograph of the combustor viewing system probe, the two illumination-carrying fibers and the angled tip of the imaging bundle can be identified by the backlighting. The probe is 1.25 cm in diameter. The photograph shown in figure III-4 of a combustor fuel nozzle in a PW 2037 engine was recorded through the combustor viewing system while the engine was operating at full power. Operating experience was also obtained in a high-pressure turbine component test facility at Lewis and at a hot gas facility at the Naval Air Propulsion Center.

Not all of the optical systems under research at Lewis involve laser excitation. The rainbow schlieren system (refs. III-11 to III-13), developed at Lewis, uses a bull's-eye color filter to add a continuous color spectrum to the classic black-and-white, "knife-edge" flow visualization technique in order to enhance index-of-refraction gradients such as those accompanying shock waves. Not only does the color aid the eye's sensitivity in perceiving minor flow features, it adds a potential for quantitative flow analysis by color coding the magnitude of refractive index changes in those flows exhibiting simple geometries. This schlieren system has been installed in the Lewis 10- by 10-Foot Supersonic Wind Tunnel. The black-and-white copy of a color photograph shown in figure III-5 illustrates the flow visualization for a supersonic side inlet tested in the tunnel. Color gradations across the shocks (visible here as different shades of gray) can be used to evaluate shock strengths and geometries.

In many areas of measurement technology, the available commercial instrument systems satisfy research needs. Optical droplet sizing systems appear to be adequate for most aeropropulsion-related applications such as fuel-spray and icing research. But important questions remain on the proper use and calibration of these instruments. We are conducting comparison tests on the most useful systems to better define their operating regimes (droplet size, droplet concentration, droplet velocity, etc.) and are also developing adequate calibration tools and techniques (refs. III-14 to III-17).

Shown in figure III-6 is a cloud droplet sizing instrument used on the Lewis Twin Otter aircraft during icing research. This instrument measures the size of single droplets (from about 2 to 50 μm) as they pass through a small probe volume defined by a laser beam and the collection optics contained in the cylindrical extensions at the front. Techniques to better calibrate this and similar optical instruments are being developed and evaluated. Shown in figure III-7 is a rotatable calibration reticle with precisely-sized spots used to simulate droplets passing through the probe volume of the instrument. The effects of droplet velocity and trajectory within the probe volume can be determined. In addition to the development of calibration techniques and hardware, a comprehensive computer analysis of several light-scattering based instruments has been undertaken to enable a thorough understanding of the limits to accuracy and operating regimes. These analyses have led to the design of applications-specific corrective optics to extend the usable operating range of commercial instruments.

Our present program in optical instrumentation research is driven by the needs of the aeropropulsion researcher and aided by the advances in optical and electronic technology. Prevalent needs are dynamic data, including time correlation between two or more parameters, and rapidly acquired whole-field data maps. The need to obtain data rapidly, always important in high-operating-cost facilities, becomes critical in some aeropropulsion research areas (e.g., limited run-time hypersonic blowdown facilities). Fiber optics and new solid-state lasers are two of the important ingredients for rugged diagnostic systems to be used in aeropropulsion facilities. The use of fiber optics as a light-carrying conduit in instrumentation systems is already widespread; solid-state lasers are just starting to mature enough to be considered as components in instrumentation systems. Laser spectroscopy, including the techniques of laser-induced fluorescence and various Raman spectroscopy configurations, has been extensively researched in the laboratory and will be moving into increasingly harsh facility environments as the supporting technology matures. There is also a strong potential for the application of artificial intelligence to complex optical diagnostic systems, both for the interpretation of whole-field data and for the alignment, both initial and corrective, of these systems.

A brief review of recent and future research at Lewis on optical measurement techniques for aerospace propulsion research has been presented. Although the techniques being investigated can be applied to meet measurement needs in many fields of research, the goals of this instrumentation research are to satisfy the very demanding measurement needs necessary to advance aeropropulsion technology.

TABLE III-I. - NONINTRUSIVE RESEARCH INSTRUMENTATION FOR AEROPROPULSION SYSTEMS

Technique	Parameters
Laser anemometry	For average flow velocity, flow angle, turbulence intensity
Holographic interferometry	For gas density changes, surface displacements
Laser spectroscopy	For gas temperature, constituents, velocity, pressure
Particle sizing	For fuel spray and cloud droplet diameters
Laser speckle systems	For surface strain
Rainbow schlieren	For flow visualization
Hot section viewing system	For monitoring hot section phenomena

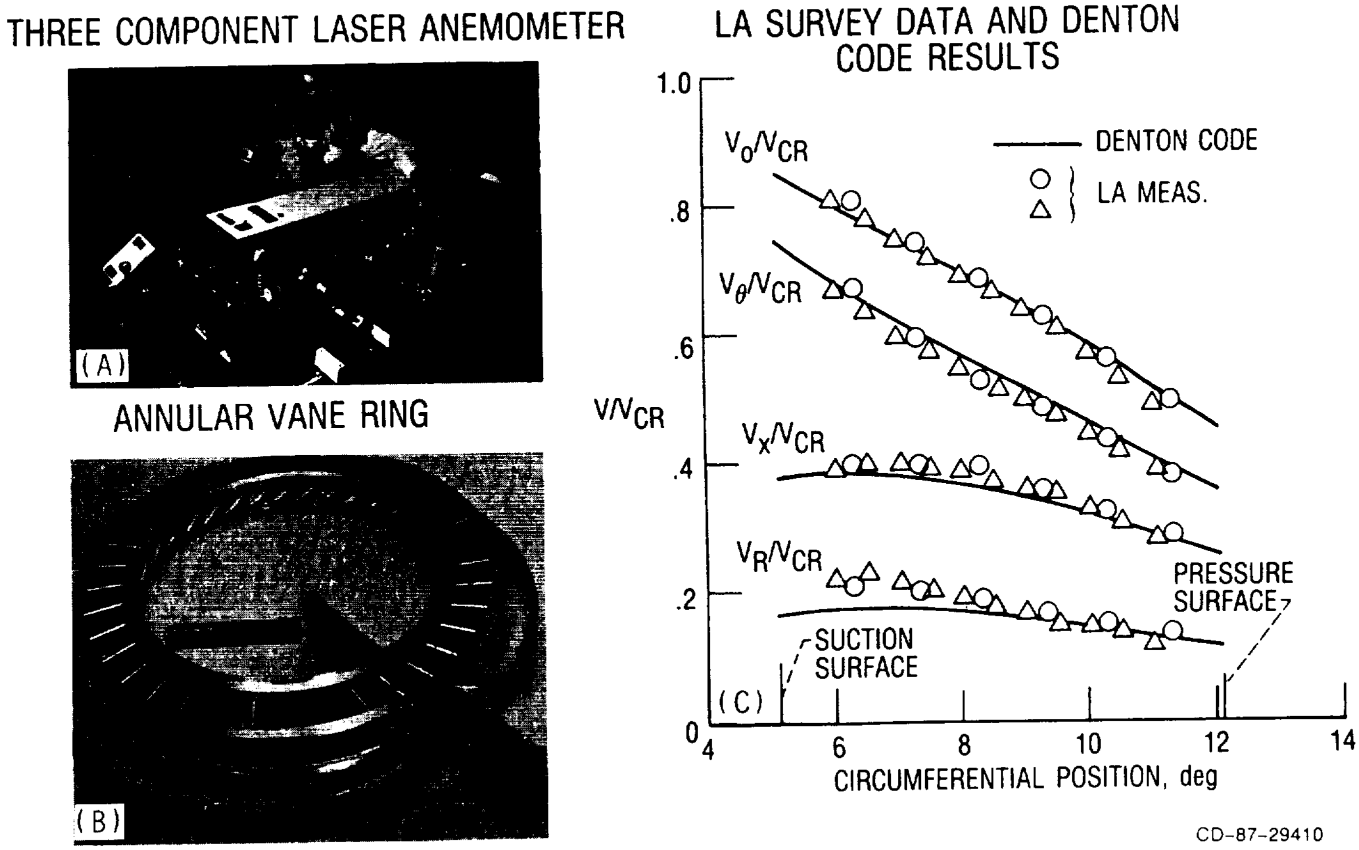

Figure III-1. - Three-component laser anemometry system.

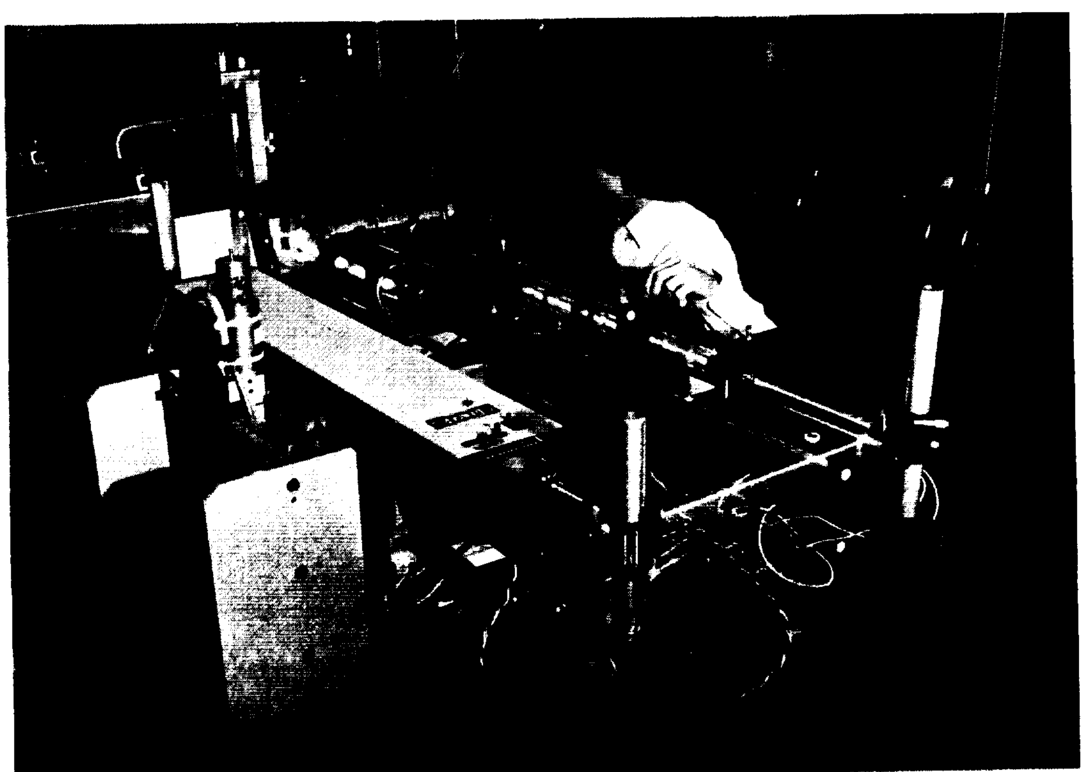

Figure III-2. - Testing of four-spot laser anemometry in open jet burner facility.

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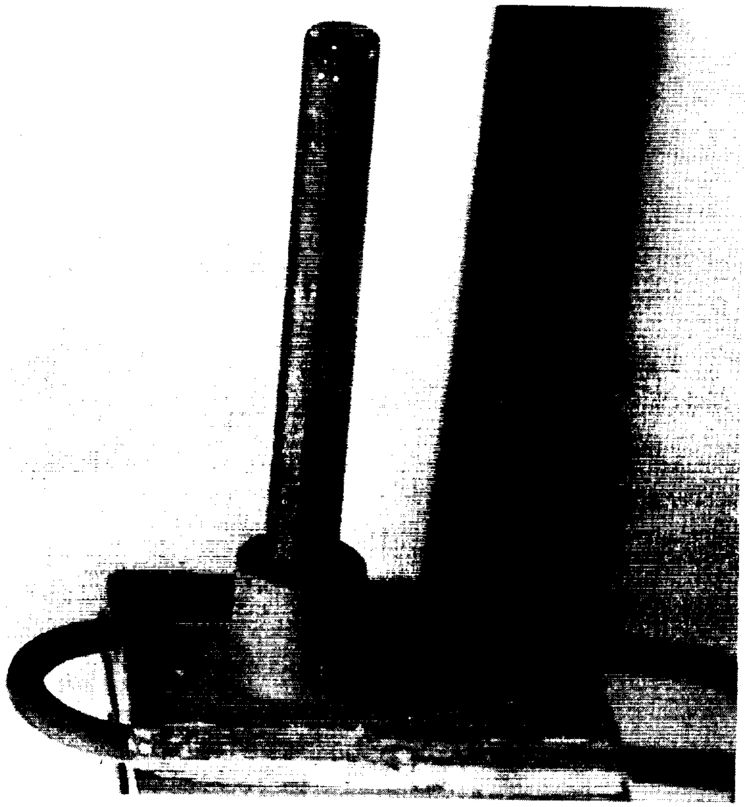

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Figure III-3. - Combustor viewing system probe.

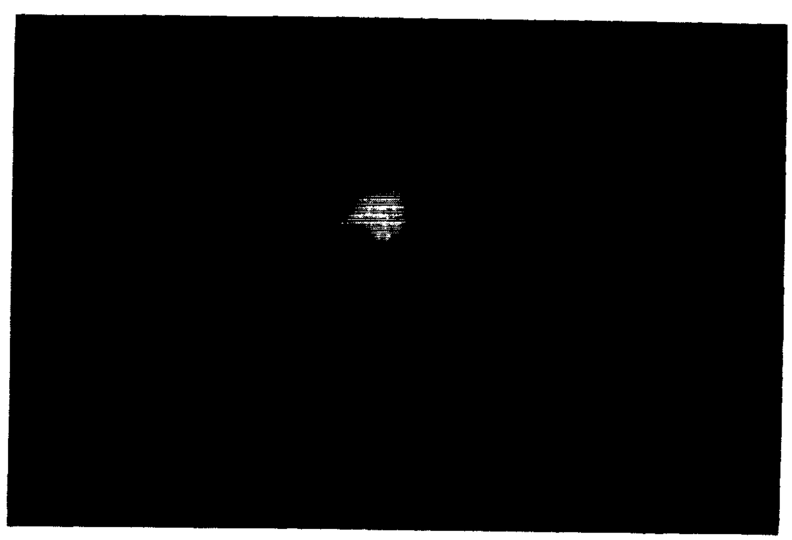

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Figure III-4. - PW 2037 engine fuel nozzle at full power.

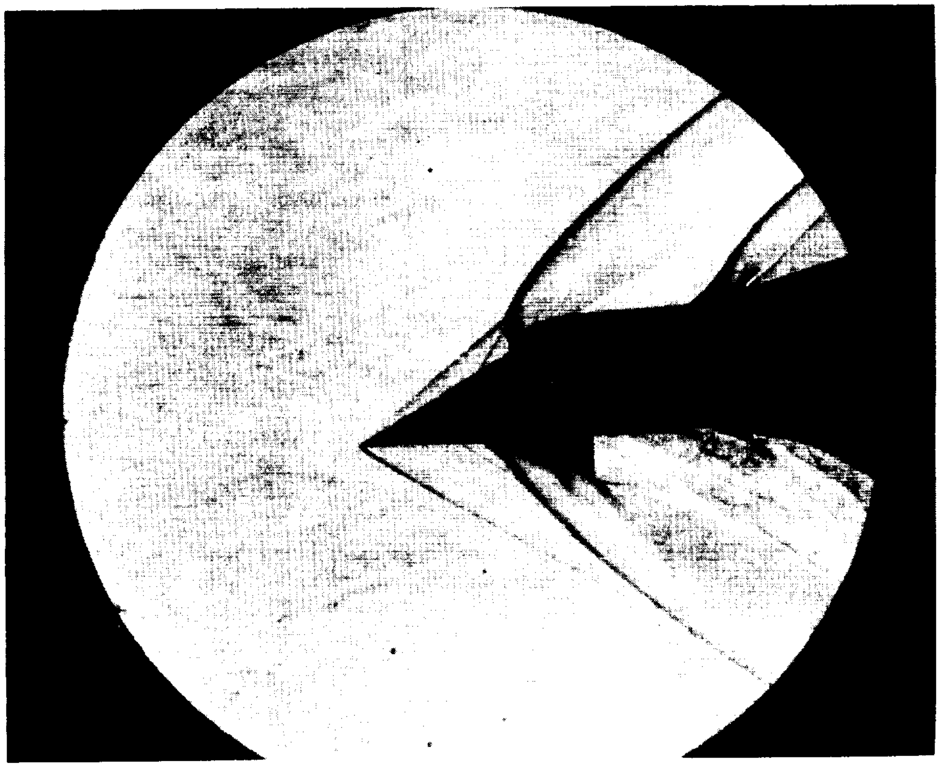

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Figure III-5. - Rainbow schlieren photograph of supersonic inlet tested in 10- by 10-ft wind tunnel at Lewis.

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Figure III-6. - Droplet sizing instrument used in icing flight research.

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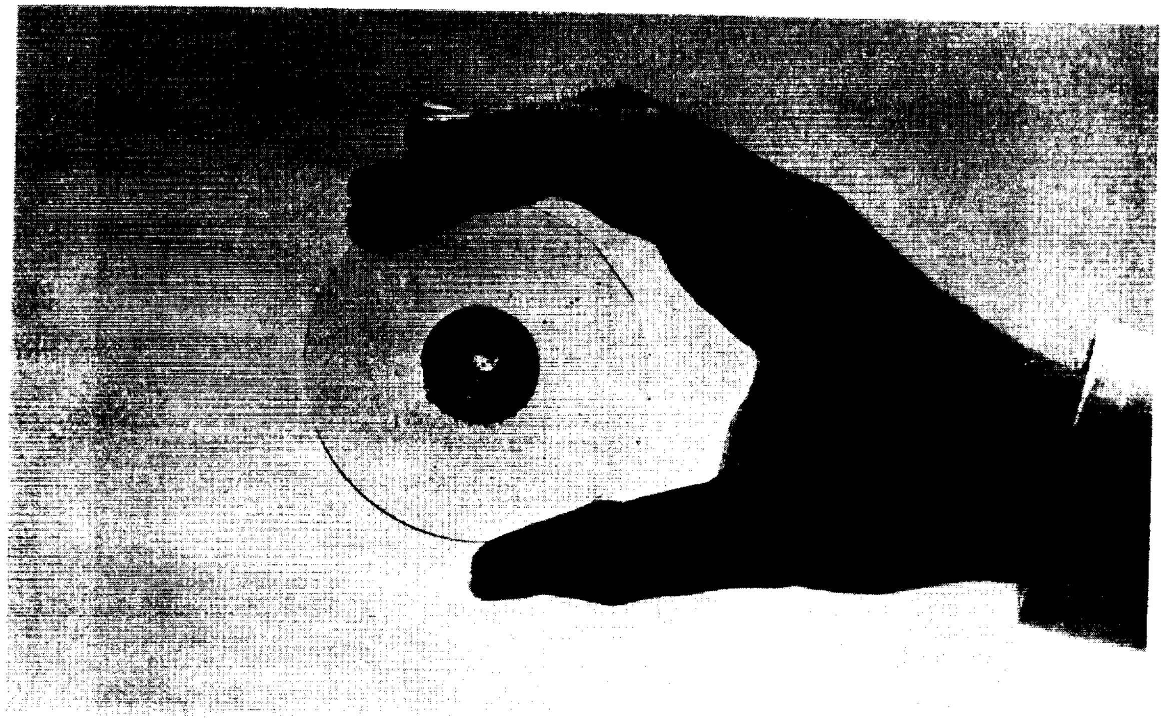

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Figure III-7. - Calibration reticle for droplet sizing instrument.